Cruzane Mountain
Soil Report

Prepared by:

Eve Wills
Soil Scientist
R1 NEPA Strike Team

for:
Superior Ranger District
Lolo National Forest

02/07/20

Introduction

The Cruzane Mountain project proposes to use a variety of vegetation treatments to restore forest resilience and reduce insect and disease problems which have increased the current risk of severe wildfire within the project area. This soil report analyzes the anticipated effects of vegetation management activities, including commercial harvest operations, non-commercial thinning, and prescribed fire. The management activities proposed for this project are shown in Table 1.

Table 1. Commercial and Non-Commercial Vegetation Treatments proposed for the Cruzane Mountain project.

Treatment Types	Acres	Number of Units
Commercial Regeneration Harvest (includes shelter wood, seed tree, and clear-cut with leave trees)	981	41
Commercial Thinning	417	19
Commercial Improvement Cut	13	1
Non-commercial thinning	77	4
Fuel Break	15	2
Ecosystem Management Burns (prescribed burning)	1161	3
Total Treatment Acres	**2664**	**70**

Summary

The treatments proposed for the Cruzane Mountain project meet the intent of the National Forest Management Act and the Lolo Forest Plan. With the implementation of design criteria for soils protection, the management actions will meet Region 1 Soil Quality Standards for maintaining productivity and limiting detrimental disturbance.

1. The project proposal includes design criteria and mitigations that would allow for soil recovery and nutrient cycling through gradual increase of soil organic matter over time. The proposal meets the Lolo NF Forest Plan, the R1 SQS, and the National Forest Management Act for the management of soil resources. Soil disturbance would occur; however, soil quality would be maintained and recovery from ground-disturbing activities would occur over time.

2. Field visits were conducted to identify possible soils issues, which revealed low levels of existing disturbance. Site-specific design criteria and soil rehabilitation will be applied as needed to maintain R1 Soil Quality Standards.

3. Lolo National Forest soil monitoring, as well as soil monitoring conducted on other National Forests in Western Montana and Northern Idaho indicates that soil disturbance from vegetation management activities is not irreversible; following disturbance there is improvement of soil function as vegetation recovers.

Regulatory Framework

Based on this analysis, the Cruzane Mountain Project maintains soil productivity and complies with goals and objectives found in National Forest Management Act, the Region 1 Soil Quality Standards, the Lolo Forest Plan, as well as other pertinent laws and regulations.

The regulatory framework providing direction for protecting soil resources to sustain vegetative productivity and other environmental functions is shown in Table 2.

Table 2. Regulatory Framework

Law/Regulation/Policy	Applicability
The National Environmental Policy Act (NEPA) of 1969 (16 U.S.C. 4321).	The Act requires analysis of the physical, social, and economic effects associated with proposed plans and decisions, to consider alternatives to the action proposed, and to document the results of the analysis.
The Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974 (16 U.S.C. 1600-1614) (as amended by National Forest Management Act (NFMA) of 1976 (16 U.S.C. 472a) Sections 3, 5, 6	NFMA requires that management "…will not produce substantial and permanent impairment of the productivity of the land" … and that soils, "…will not be irreversibly damaged" (16 USC 1604(g) (3) I and 16 USC 1604(g) (3) I (i)).
Forest Service Manual 2550. Soil Management, WO Amendment 2500-2010-1	To manage resource uses and soil resources on National Forest System lands to sustain ecological processes and function so insure desired ecosystem services are provided in perpetuity.
Forest Service Manual 2550. Soil Management, R1 Supplement 2500-2014-1.	To meet direction in the National Forest Management Act of 1976 and manage National Forest System lands in Region 1 under ecosystem management principles without permanent impairment of land productivity and to maintain or improve soil quality. This regional policy also defines the allowable extent of soil disturbance to maintain soil productivity, thus meeting the intent of the National Forest Management Act (USDA 1976).
Lolo National Forest Plan, 1986	Forest-wide Management Direction was established to protect the watersheds and forest soils (Chapter II: 12-13)

These regulations insure forest management activities are designed to maintain or improve the capacity of the soil resource, including the physical, chemical, and biological components needed to support site productivity that allows for management objectives to be achieved, including the growth of specific plants, plant communities, or a sequence of plant communities (FSM Watershed and Air Management, Chapter 2550 Soil Management, page 9).

Methodology

Indicators, Measures, and Thresholds

The Forest Service, Northern Region (Region 1) Soil Quality Standards (USDA 2014) defines the degree and extent of disturbance allowed for management activities, while still maintaining soil productivity, thus meeting the intent of the National Forest Management Act (USDA 1976). As defined by the Region 1 Soil Quality Standards, at least 85 percent of an activity area must retain soil quality in an unimpaired condition. Forest Service Manual Section 2550 (USDA 2010) and the Region 1 Supplement 2500-2014-1 (USDA 2014) provide the regulatory guidance for maintaining productivity during management activities.

Physical variables influencing soil productivity include texture, structure, coarse fragments as well as organic matter and biological activity (Dumroese et al. 2006). Soil functions, as they relate to soil productivity, can be difficult to assess without detailed laboratory analysis. Therefore, indicators of detrimental soil disturbance leading to impairment of soil productivity were collected in the summer of 2019 during field visits to the proposed mechanical treatment units using the protocols and methods outlined in the Region 1 Soil Disturbance Technical Guide (USDA 2009). Table 3 describes the indicators used to estimate impacts on long-term soil productivity.

Table 3. Soils Resource Measures

Visual Indicators of Detrimental Soil Disturbance	Measurement (FSM 2500-2014-1)
Soil compaction	Detrimental compaction is a reduction in pore space associated with decreased infiltration and increased erosion potential. Severity of compaction may be indicated by size and depth of massive or platy soil structure.
Rutting	Wheel ruts greater than 2 inches deep in wet soils.
Soil displacement	The absence or removal of 1 or more inches of any surface horizon and its duff layer, from a contiguous area greater than 100 square feet.
Surface erosion	The presence of rills, gullies, pedestals, and/or areas of soil deposition are all visible indicators of surface erosion.
Severely burned soils	High intensity burns of long duration which cause physical (altered structure and color) and biological (fertility and nutrient cycling) changes to soil are detrimental. Guidelines for assessing changes to soils after a fire are contained in the Field Guide For Mapping Post-Fire Soil Burn Severity (Parsons et. al., 2010)
Soil mass movement	Any potential for soil mass movement to be exacerbated by management activities is considered detrimental.

In Region 1, the six above indicators were developed for quick assessment of soil conditions. As an example, soil compaction can have a negative effect on plant root development by decreasing soil porosity and water infiltration. When soil functions are negatively affected, long term soil productivity may be impaired.

Data Sources and Methods

A combination of data derived from spatial analysis and field survey was used to analyze effects to the soil resource from proposed activities. Field surveys were completed during the summer 2019 and included site visits to a total of 58% of treatment units; 82% of ground-based harvest units and 50% of skyline/excaline harvest units. Information from units surveyed was combined with remote sensing analysis and extrapolated to un-surveyed units. Given the relatively small project size, consistency of parent materials and prior activities, this is an appropriate method for analysis. Table 4 provides a summary of field visits.

Table 4. Summary of Units Surveyed*

Treatment Type	*Number of Units Surveyed*	*Percent of Total*
Proposed Ground-Based Harvest	14	82%
Proposed Skyline (or Excaline) Harvest	17	50%
Proposed Combination Treatments including: Skyline/Tethered, Tractor/Excaline, Tractor/Skyline	5	45%

* This table displays proposed activity areas surveyed with transects and walk-through methods for assessment of soil condition during the summer of 2019.

Spatial Analysis

GIS analysis utilized geospatial data from several sources. GIS layers used in soil analysis include:

- USGS Wallace 10 x 20 Geologic Quadrangle, clipped to Cruzane Mountain Project Boundary
- Lolo National Forest Land System Inventory - Sasich and Lamotte-Hagen 1989; featureclass clipped to treatment boundaries.
- 10 meter digital elevation model (USGS), used to generate terrain products (slope, hill shade, elevation) using ArcGIS 10.5 Spatial Analyst tool set
- Roads and trails (Lolo National Forest)
- Stand harvest and burn history from the FACTS database, 1910 to present (Lolo National Forest), clipped to project boundary
- Aerial imagery, USDA, National Agricultural Imagery Program (NAIP), 2017
- World Imagery (Clarity, high resolution) - Source: ESRI, DigitalGlobe, USGS
- Black and white Digital Ortho-photo mosaic 1990s - U.S. Geological Survey, Montana State Library

In addition to field surveys, remote sensing also aided in resource analysis and was used as a tool to assess conditions in units. A variety of aerial imagery, including black and white imagery from the 90's was utilized to locate areas of impacts from past activities, while current imagery provided high resolution views of current vegetation conditions and disturbance in the project area, including old road prisms and other remaining treatment disturbance. Generally, disturbances on south facing aspects were easily visible, while tree canopy tended to obscure some, though not all signs of soil disturbances on north facing aspects.

Field Surveys and Data Collection

Information regarding existing soil conditions was collected during field visits during the summer of 2019. In accordance with the guidelines in the R1Soil Disturbance Monitoring Protocol (Dumroese et al. 2009), a combination of transects and walk-through surveys was used to quantify existing soil disturbance and ecological function on a majority of units. Additional site and soil characteristics were collected including forest floor coverage and coarse woody debris information. Coarse woody debris was measured using three 100 foot transects per unit following protocols established by the Lolo National Forest (USDA 2006). During the surveys, areas of sensitive soil (shallow soils, unmapped seeps or wet areas, ephemeral drainages, slopes on excess of 35 percent) were noted. A summary spreadsheet for surveyed project units can be found in the project file.

The Region 1 Soil methodology provides a conservative estimate of existing soil quality, as the protocol tends to overestimate the amount of detrimental soil disturbance (Dumroese et al. 2006; Miller et al. 2010). Using the R1 soils protocol provides a 70-80% confidence level of detecting up to 15% detrimental disturbance.

Spatial and Temporal Context for Effects Analysis

Spatial Scale

Soil productivity is site specific to the area where land management treatments occur. Loss of soil productivity in a treatment unit does not affect soil productivity in an adjacent unit or areas across a watershed. Assessment of soil quality within a large area (such as a watershed), which would include both activity and non-activity areas, would dilute detrimental effects at the site where the treatment is taking place. Therefore, the units proposed for mechanical harvest form the spatial boundary for the soils effects analysis. As described in the Region 1 Supplement 2500-2014-1 (USDA 2014), an activity area is defined as: “a land area affected by a management activity to which soil quality standards are applied. Activity areas must be feasible to monitor and include harvest units within timber sale areas, prescribed burn areas, grazing areas or pastures within range allotments, riparian areas, recreation areas, and alpine areas”.

Temporary roads directly associated with a treatment unit, as well as skid trails and landings are considered to be part of an “activity area” (USDA 2014). Roads that are included in the forest transportation system are not considered for detrimental soil disturbance, as their footprint has already removed from the productive land base.

Temporal Scale

The temporal scale for assessing soil resource effects includes both short- and long-term impacts. For the purposes of this analysis, short-term effects are defined as those that occur within 10 years following proposed vegetation treatments. Long-term effects are defined as those that occur 10 to 20 years or more following proposed vegetation treatments.

Soil Resource Issues

Soil resources will be discussed based on the framework of the Lolo Forest Plan and the R1 Soil Quality Standards (SQS). Soil resource concerns are framed in the context of soil productivity (including measures of detrimental soil disturbance and organic matter) and soil stability (soil erosion potential and detrimental soil disturbance). While some soil disturbance is unavoidable from forest management activities, it is minimized using site specific resource protection measures and project wide standard operating procedures which significantly reduce long-term, detrimental impacts.

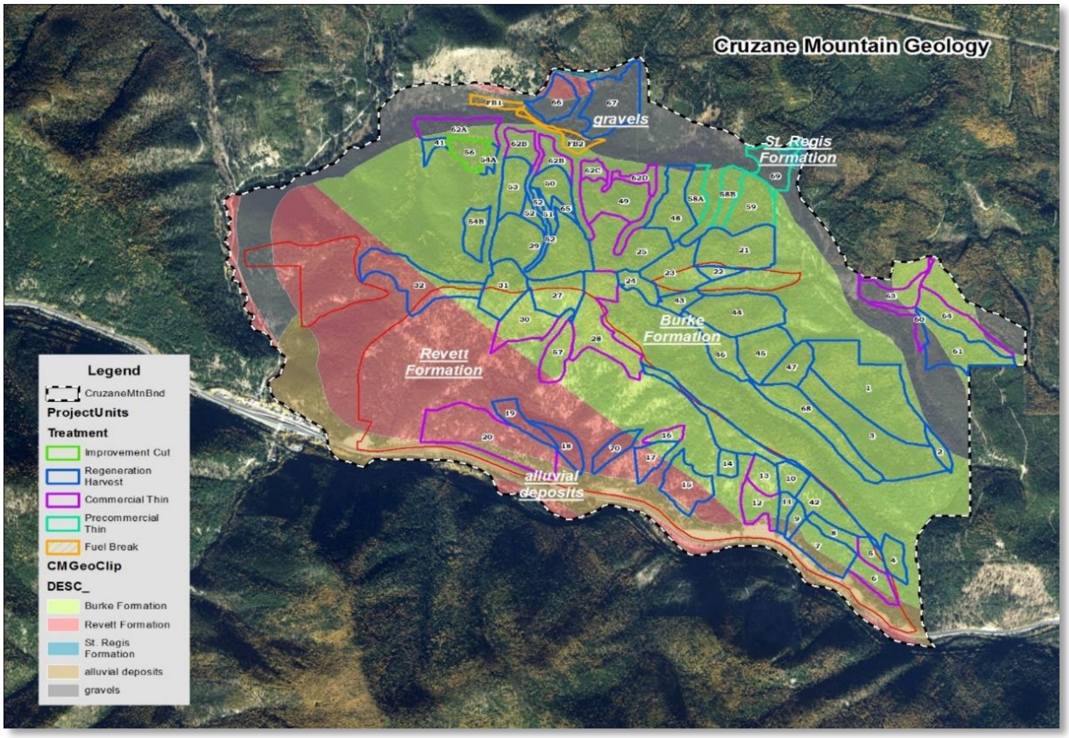
Affected Environment/ Existing Condition

Geology and Geomorphology

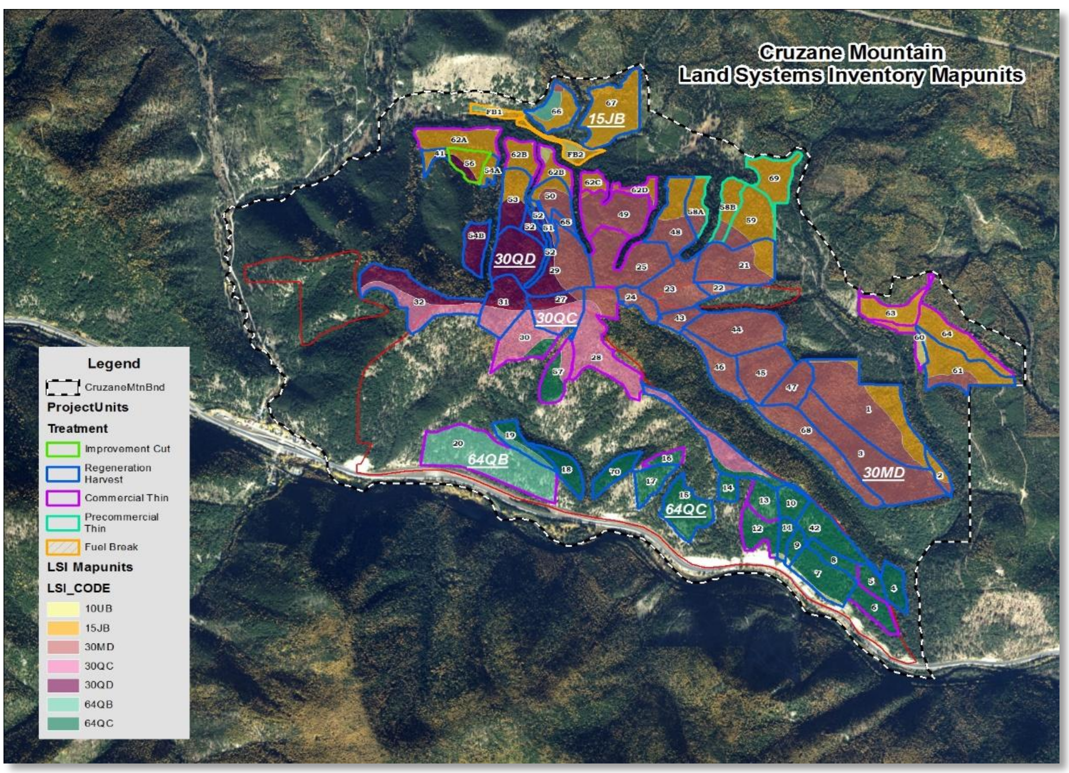
The geology of the Cruzane Mountain Project area is dominated by Proterozoic metasedimentary rocks of the Revett and Burke Formations of the Belt Supergroup (USGS 2000), on moderately steep and steep mountain slopes. Minor valley fill and alluvial deposits occur on the lower-sloping parts of the project area (USDA Forest Service 1989). The dominant bedrock is expressed as highly resistant quartzites and argillites, which comprise about seventy-seven percent of the project area (Map 1; p.6). Quartzite tends to form stable soils in gravelly colluvial deposits with sandy loam textures. Such soils tend to be resistant to erosion as well as mass movement.

Mount Mazama, a volcano in the southern Cascade Range (currently the site of Crater Lake National Park) erupted approximately 7700 years before present, blanketing much of the Pacific Northwest with a cloud of ash (Bacon and Lanphere 2006). Where pure ash deposits are found, soils may be more prone to surface soil compaction, but ash deposits can also result in higher soil productivity associated with greater water holding capacity and nutrient availability (McDaniel and Wilson 2007). Ash deposits found in activity units in the Cruzane Mountain project tend to be intermittent, thin and mixed with a variety of sources (Kimsey et al. 2007), mostly in the form of eolian deposition on north slopes by prevailing winds removing it from south slopes.

Map1. Geology of the Cruzane Mountain Project area



Map 2. Soil Mapunits of the Cruzane Mountain Project Area



Cruzane Mountain Soil Mapunits

Soils on the Lolo National Forest were mapped as part of the Lolo Land Systems Inventory {USDA Forest Service 1989} (which includes soil profile descriptions, vegetation observations and interpretations of such characteristics as potential for natural regeneration, surface erosion potential, sediment delivery and mass failure potential; Map 2, p.6). The dominant landforms in the Cruzane Mountain project area include mountain slopes, while stream bottoms and foot slopes occupy a much smaller proportion. Table 5 displays Land Type map units and interpretations for units that will receive mechanical treatment. Units designated for treatment by hand are not included, as hand treatment does not cause additional soil disturbance.

Table 5. Lolo National Forest map units and Interpretations for Cruzane Mountain Mechanical Treatment Units

Map Unit	Mechanical Treatment Units	Landform	Natural Regeneration Suitability	Surface Erosion Potential	Sediment Delivery Potential	Mass Failure Potential	% of Treatment Acres
10UB	60, 61, 62B, 67	Stream bottoms	Poor; high water table	High	High	Low	.4
15JB	1, 2, 21, 3. 41, 48, 49, 50, 52, 53, 54A, 56, 60, 61, 62A, 62B, 62C, 62D, 63, 64, 66, 67	Toeslopes and alluvial fans	Good	High	Low	Moderate	19
30MD	1, 2, 21, 22, 23, 24, 25, 27, 28, 29, 43, 44, 45, 46, 47, 48, 49, 50, 51, 61, 62C, 62D, 65, 66, 68	Moderate relief mountain slopes	Good	Moderate	Low	Low	38
30QC	27, 28, 30, 31, 32, 42, 57	Moderate relief mountain slopes	Good	Low	Low	Low	10
30QD	27, 29, 30, 31, 32, 41, 51, 52, 53, 54B, 56	Moderate relief mountain slopes	Good	Low	Low	Low	9
64QB	19, 20, 66	Steep mountain Slopes	Fair; grass competition	Low	Moderate	Low	6
64QC	4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 30, 42, 57, 70	Steep mountain Slopes	Good	Low-Moderate	Moderate	Low	18

Soil Characteristics in the Cruzane Mountain Activity Units

Surface Erosion Hazard

Soil erosion involves the breakdown, detachment, transport, and redistribution of soil particles by forces of water, wind, or gravity (NRCS 2007). The Landtype ratings were determined based on measured observations of exposed surfaces on varied slope and soil conditions within the map unit survey area. Surface erosion potential is low to moderate for the majority of soils in the project area, except in mapped stream bottoms (map unit 10UB) and toe slopes (map unit 15JB), constituting approximately 20% of mechanical treatment areas (Table 5). Field review of the majority of treatments units containing these land types found no soil concerns for standard ground-based logging operations. For all other soils in the project area, high vegetative cover and rock content in the soil profile results in increased infiltration and decreased runoff, thus reducing the surface erosion potential. Soils in the project area are stable in their undisturbed state.

Mass Failure Potential

Mass failure potential is the down-slope movement of a large volume of unconsolidated material under natural conditions. Besides natural failure, mass movement can be triggered by mechanisms such as harvest activities, severe burning and road building, particularly with over-steepened road cuts. Indicators of landslide prone areas may include random seeps and wet areas, steep slopes, substrata with shrink-swell clays, pistol butted trees, and hummocky topography. Mass failures result in loss of soil structure due to mixing of surface and subsurface horizons resulting in deterioration of productivity and inherent instability for existing and future vegetation. Although none of the soil map units in the Cruzane Mountain Project area raised concern for mass failure under normal operating procedures, hydrological modeling indicated an elevated risk of mass failure in treatment units 18 and 19 due to steepness and possible wetness. Therefore, these units will receive additional field evaluation to determine feasibility of harvest operations (see Project Design Feature #7, p.11)

Natural Regeneration Suitability

Natural Regeneration Suitability is the capacity of the physical, chemical, and biological components to support resource management objectives without degradation of the soil resource. It includes the potential for growth/regrowth of specific plants, plant communities, or a sequence of plant communities (Dumroese et al. 2010). The majority of soil types associated with activity units in the project area are productive and resilient to management activities (Table 5).

Sensitivity to Disturbance

The majority of the soil types in the Cruzane Mountain project area are resilient to soil disturbances associated with logging operations. Units that have soil sensitivity concerns as they contain soil map units 10UB and 15JB, were evaluated during field analysis and found not to have issues that would preclude the use of machinery. Some minor areas with previous harvest have residual logging features that will be reused to minimize additional disturbance, and then reclaimed.

Existing Soil Condition

For the soils resource, existing condition includes an assessment of existing soil disturbances resulting from past management activities or natural processes. Existing disturbance within units was measured during field visits. Existing detrimental soil disturbance, soil disturbance that may indicate permanent site impairment or soil productivity issues (R1 Supplement No. 2500-14-1 2014), is also recorded during field visits. Estimates of existing disturbance for each unit can be found in Appendix A, pp. 22-23.

Past Harvest Activities

Approximately 1234 acres of past harvest activity (32%) has occurred on National Forest Land within the project area, with most activity occurring in the 1970's. Existing harvest related disturbance was noted within activity units during field surveys. Impacts to soil productivity were typically confined to old roads and landings. Outside of areas directly adjoining roads, the units showed little or no detrimental soil disturbance from past harvest activities. The amount of past soil disturbance observed is accounted for in the existing condition. A summary of existing condition for treatment units is included in Appendix A., pp. 22-23.

Previous harvest in the project area were mostly related to types of commercial thinning with many of the roads, skid trails, and landings that will be used for the Cruzane Mountain project constructed during this period. Signs of soil disturbance directly related to harvest outside of old road prisms has largely dissipated through natural processes such freeze/thaw and wet/dry cycles as well as the regrowth of vegetation and accumulation of fine and coarse organic material.

Coarse Woody Debris and Organic Matter

Organic matter and coarse woody debris are good indicators of site resiliency and overall forest health. Organic matter, including the forest floor duff layers and large woody material, is essential for maintaining ecosystem function by moderating soil temperatures, improving water availability, and adding to microbial biodiversity (Dumroese et al. 2010).

Coarse Woody Debris

Part of the purpose and need of the Cruzane Mountain Project is to restore vegetation conditions that are resilient to natural disturbances by reducing forest fuels. This objective includes reducing the amount of downed timber from the forest floor where it exceeds standards while continuing to provide organic matter inputs for continuing soil productivity. Project activities would reduce fuel loading where necessary, but coarse woody debris levels would remain within the acceptable ranges of the Lolo National Forest Woody Material Guidelines (USDA 2006) and Graham et al. (1994).

All surveyed units met or greatly exceeded the Lolo NF Coarse Woody Material Guidelines (USDA 2006). Coarse woody material was represented within project units in several size classes, from wood less than 3 inches in diameter to wood greater than twelve inches in diameter.

Forest Floor Duff and Litter

Soil cover from organic matter and vegetation averages greater than 90 percent across all units of the project. Small areas of bare soil were generally localized locations on south slopes or on former landings. Depth of litter and duff was greater than 1 centimeter through all units visited.

Canopy and shrub cover contribute to soil organic matter through yearly shedding of leaves. Canopy cover serves to provide shading of the soil surface and is an important component of forest nutrient cycling. Vegetation management may create openings in the canopy, increasing plant diversity due to added sunlight and moving them towards increased resiliency while creating more wildlife habitat.

Organic matter can be improved by human activity. Manipulation of the organic constituents can lessen the effects of timber harvest and fuels reduction treatments on soil resources (Sawyers et al. 2012). Of the many organic materials incorporated in a forest soil, the woody component (fine and coarse) is the most important. To protect the productivity of the forest soil and its biome, a continuous supply of organic materials must be provided (Brown et al. 2003, Graham et al. 1994).

Roads

The Cruzane Mountain project area includes approximately 16 miles of National Forest System Road. These system roads, whatever their condition, are part of the forest travel management plan. Region 1 soil quality standards do not apply to system roads as their footprint has been removed from the productive soil base (R-1 Supplement 2550-14-1, 2014). System roads utilized within the Cruzane Mountain project will be treated using best management practices (BMPs) to protect soils from erosion and potential for mass failure associated with poor drainage (National Best Management Practices for Water Quality Management on NFS Lands, 2012). The Cruzane Mountain project proposal includes 4.4 miles of new temporary road construction, which will be obliterated following treatment by applying slash and/or reseeding. In addition, 5.5 miles of existing system road will be decommissioned, reclaimed, and removed from the road system.

Environmental Consequences

Soil disturbance is an unavoidable consequence of forest management activities. Best management practices, standard soil operating procedures, design criteria are applied to reduce disturbance and limit negative effects to soil resources. Direct, indirect, and cumulative effects of the proposed activities on soil resources will be analyzed in terms of R1 SQS and the resource indicators present in Table 3.

Alternative 1 – No Action

Alternative 1 maintains the existing soil conditions on the landscape and would result in no new soil disturbances. With no activities proposed in Alternative 1, the existing soil conditions described above would remain, and opportunities for soil resource benefits associated with Alternative 2, including low severity prescribed fire and road decommissioning, would not occur. Alternative 1 meets the regulatory guidance of the Lolo National Forest Plan, R1 Soil Quality Standards, and the National Forest Management Act (NFMA) for soil resources, as no action would result in maintenance of the existing soil conditions.

Alternative 2 – Proposed Action

Alternative 2, the Proposed Action, proposes to restore vegetation conditions to resilient forest systems, which will be achieved through commercial timber harvest on a total of 1,411 acres. In addition to commercial harvest proposals, the Cruzane Mountain project also proposes non-commercial fuel treatments and pre-commercial hand- thinning on approximately 92 acres, and low and mixed severity prescribed fire on 1161 acres.

Soil Project Design Features and Mitigation Measures

Design features and mitigation measures are identified during field assessments in order to address site specific resource concerns and mitigate existing disturbances. The objective of soil design features and mitigations is protection of soils during mechanical harvest operations to minimize damage caused by movement of heavy equipment. The design features and mitigations include standard best management practices and measures for coarse woody debris retention where needed, skid trails and landings, temporary roads, and specifications for summer operations within the project area.

Summer Harvest Guidelines - Activities must be conducted over dry ground (as shown in Appendix B)

1. The standard dry-ground Equipment Operation Period is June 15 to Sept 15, but may extend beyond as long as dry conditions exist.
    - i. Dry conditions (as shown in Appendix B) must exist on greater than 85% of the harvest unit (including the landings)
2. Field observations to determine if soils are sufficiently dry for equipment to operate are:
    - i. If the soil forms a clod from the upper 6 inches of soil, it is too wet to work OR
    - ii. As displayed in Appendix B.

3. Skid trails would generally be designated 75 feet apart with consideration given to the unit and equipment/operator capabilities.

4. Dispersed skidding may be used depending on the amount of material to be removed, shape of the unit, and equipment to be used. Designate skid trails where machine traffic would be high, *for example* close to landings.

5. Sale administrator would be given the flexibility to disperse or designate skid trails based on site-specific conditions with consultation by an FS Soil Scientist, with the objective of meeting Region 1 Soil Quality Standards.

6. Units 23, 44, 45 and 47 are designated for skyline/tethered harvest. This yarding system has been included to provide flexibility for harvest on slopes at upper limits for operations. Ongoing research performed in Region 6 (Sessions et al. 2017) indicates tethered harvest may be effective at reducing harvest-related soil disturbance. These units will require monitoring during implementation. If higher than expected levels of disturbance are found during implementation, the remainder of skyline/tethered units will be treated using skyline only.

7. Hydrological modeling indicated the possibility of elevated mass wasting potential for units 18 and 19. Therefore, a forest hydrologist or soil scientist will visit these units prior to implementation to evaluate stability and/or wetness in areas of steeper slopes. Feasibility to harvest these units will be reconsidered after completion of field reviews and coordination with Silviculture/Timber Management or Sale Administrator and the District Ranger.

8. Where feasible, existing road prisms, skid trails and landings as well as other areas of disturbance will be favored over creating new areas of disturbance.

9. Stationary skid turns and side-slope movement of harvest and skidding equipment between designated trails would be minimized.

10. Harvest and skidding equipment would be restricted from operating in areas with greater than 35% average slope except for short pitches (40-45% and less than 100 feet in length), unless the site is reviewed by an FS Soil Scientist.

11. A no-equipment buffer is to be placed around all ephemeral draws. The no-equipment buffer is 50 feet from the draw centerline or the top of the inner gorge. Trees can be felled to lead or lined out of the draw as long as gouging of the soil surface does not occur. Equipment may cross the ephemeral draw at designated crossings.

12. Waterbars and/or slash will be placed on temporary roads, skyline corridors or along main skid trails to prevent erosion and capture sediment.

13. Newly constructed temporary roads and landings will be obliterated upon completion of mechanical operations. Obliterating temporary roads will consist of re-contouring the road prism, including all cut and fill slopes. Logging slash, stumps, and woody debris will be placed on top of obliterated road corridors to effectively prevent illicit vehicle travel. Where re-contouring is unnecessary, or where detrimental soil disturbance has occurred on skid trails, scarify traveled surface to a depth sufficient to ameliorate the presence of detrimental soil compaction (usually between 2 and 12 inches).

14. Disturbed sites, such as temporary road corridors, landings and skid trails with high levels of disturbance will be revegetated using seed recommended by the Forest Botanist as soon as feasible after the completion of operations to prevent the spread of noxious weeds.

Skid Trail and Temporary Road Slash Placement – Slash will be placed on skid trails to reduce erosion, maintain soil productivity, reduce detrimental soil disturbance and weed spread, enhance natural regeneration and hold soil moisture.

1. Slash is to be placed on areas of bare mineral soil within the main skid trails for protection of exposed soil.
2. Duff, litter, soil, and woody material that is displaced from the trail will be placed back over the skid trail.
3. Slash and coarse woody debris (both greater than and less than 3” in size) would be placed over 65-70% of the skid trail in contact with the soil surface.

Design feature effectiveness for ground-based thinning operations

The practices to protect soil productivity outlined in the design criteria for this project have been shown to reduce the occurrence of detrimental soil disturbance to within the Region 1 guidelines specifying that at least 85 percent of the soils in an activity area must retain site productivity (USDA 2014).

Soil moisture, soil texture, profile rock, and vegetative cover all play a role in the susceptibility of the soil to damage by heavy equipment. In 1983, Froehlich et al. showed that designating skid trails greatly decreased the areal extent of soil disturbance. When skid trails were established at 100-foot spacing, 11% of a unit would be covered in skid trails (Froehlich and McNabb 1984). By the mid to late 1980s, forest practices were changing to incorporate these findings (2550 Region 1 Clarification of Soil Quality Standards 2000). Skid trails were designated, season of use considered (Flatten 2003), and practices that exposed bare mineral soil were discouraged. These and other best management practices (BMPs) and Forest Plan Standards and Guidelines were developed to manage timber resources while sustaining site productivity.

In addition to using or re-using designated skid trails and landings as specified, scientific research by McNabb et al. (2001) has demonstrated that soil compaction can be significantly reduced by limiting period of equipment operation to seasons where soils on skid trails are likely to be completely dry. Han (2006) showed that slash, a protective layer of woody debris placed in traffic areas such as skid trails is an effective mechanism for reducing the impact of heavy equipment on soils. Woody debris also serves to promote water retention and nutrient cycling. As called for in the mitigation measures, temporary roads and landings would be obliterated following commercial treatment, and then be revegetated with native seed to encourage quick return of normal biological function.

Of particular importance for protection against detrimental soil disturbance are the limitations for mechanical operations to dry soils. Scientific research by Williamson and Neilson (2000) demonstrated there was no significant compaction at 20 to 30 cm soil depth under dry forest with soils at wilting point, even after several machine passes, where compaction at similar depth increased by as much as 40 percent with the first three machine passes with wet soil conditions.

Post-harvest fuel reduction will be scheduled when soil moisture levels are high enough that fire does not consume the surface layers, which protects the soil from surface heating (DeBano 2000). Timing burning of slash piles during periods when soils are frozen or wet is proven to protect the soil from the detrimental effects of heating. Research by Frandsen and Ryan (1985) demonstrated that slash piles burned on cold, wet soil had 20 percent of the heat transfer compared to a slash pile burned on a dry soil surface, substantially reducing the potential for damage to soil organic matter and microorganisms. Therefore, to prevent detrimental soil heating, the burning of slash should take place when soil surface is cold and wet, ideally with a tall, narrow profile to reduce the surface area of soils exposed to the effects of fire beneath the piles.

Monitoring on the Lolo National Forest, as well as other National Forests in Montana between 2007 and 2018 shows that in most harvest units, including summer ground-based harvest units, detrimental soil disturbance falls well below the 15% threshold required to meet R1 SQS within 5-10 years of implementation (Lolo NF Soil Monitoring Reports 2007-2018)

Monitoring

Post-activity project monitoring is conducted using the R1 Forest Soil Disturbance Monitoring Protocol (Dumroese et al. 2009) on a random subset of project activity units. Post-activity monitoring is initiated 2-3 years following an activity to access soil recovery. Soil monitoring on the Lolo National Forest is based on the 15% detrimental soil disturbance threshold in compliance with R1 Soil Quality Standards (USDA R1 Supplement 2500-1, 2014).

Region 1 Soil Quality standards stipulate that management activities must not exceed 15 percent areal disturbance as a result of project implementation. Ideally, the planned activity should move conditions towards a net improvement in soil quality. If the 15 percent threshold for disturbance is reached, corrective actions are taken to rehabilitate the impacted site. In the Cruzane Mountain project area, commercial activity units will be randomly chosen for post-harvest monitoring.

Units that will require monitoring during implementation for the Cruzane Mountain project are 23, 44, 45 and 47, which are designated for skyline/tethered harvest. This is an option that has been included for yarding systems to provide flexibility for harvest on slopes towards upper operating limits that has been shown to reduce soil disturbance. If higher than expected levels of disturbance are found during implementation, the remainder of skyline/tethered units will be treated with skyline only.

Direct and Indirect Effects of Commercial Treatments

Direct and indirect project effects are reported below (Table 6) as they relate to soil resource indicators of soil productivity and soil stability. These resource indicators and the associated measurable attributes are used to assess project effects.

Table 6. Summary of Effects by Alternative

Resource Indicator	Indicator /Measure	Alternative 1: No Action	Alternative 2: Proposed Action
Soil Quality	Detrimental Soil Disturbance	Soil function would remain unaltered under current management for the foreseeable future with the exception of change through natural means such as wildfire or severe weather.	Project would result in 134 acres of Soil Disturbance, including 8.5 acres of disturbance created by temporary roads.134 acres equals 9% of treatment unit area, falling below the 15% threshold allowed for soil disturbance, maintaining R1 Soil Quality Standards.
Soil Burn Severity	Soil Erosion	No prescribed burning would take place; therefore, erosion and nutrient cycling rates would remain stable under current management with the exception of change through natural means, such as high-intensity wildfires.	Prescribed burns managed at low to moderate severities would preserve surface cover and soil productivity. Nutrient cycling may increase as a direct result of fire. Favorable burn conditions would allow plants to regrow from unburned roots, while improved fertility would benefit regeneration of plants from roots and seed remaining in the soil.
Soil Stability	Mass Failure Potential	No new activities would be conducted. No additional mass failure hazard or erosion would occur.	Units were reviewed in the field to identify signs of instability in units. No areas of unstable soils were observed during unit transects.

Detrimental Soil Disturbance

Primary effects to soil productivity from Alternative 2 are soil disturbance from the harvesting of and transporting of logs. Soil disturbance is considered detrimental where soil compaction, topsoil displacement, rutting, and surface erosion occurs negatively impacting soil function. Detrimental soil disturbance is anticipated to be highest in ground-based harvest units where operations are more likely to result in changes to infiltration and biologic function, leading to erosion (Han et al. 2009; McIver and McNeil 2006). Soil impacts associated with skyline, excaline and units where combined treatments occur are anticipated to be less (LNF 2018). Detrimental soil disturbance by harvest method is summarized for each unit in Appendix A, pp.22-23.

Summary of Direct Effects

Alternative 2 proposes commercial harvest on 1,411 acres, resulting in an estimated 134 acres of total detrimental soil disturbance within proposed activity units (9% of total Alternative 2 treated acres). Included in this acreage is 4.4 miles (8.5 acres) of temporary roads (4.4 miles = 23,255 feet x 16 feet of width/43,560 (square feet in an acre) equaling 8.5 acres). This disturbance is contained within the footprint of harvest operations. Soil productivity would be maintained since project related soil disturbance would dissipate with time and the overall DSD created during activities is well below the 15% Regional threshold that could signal long-term impairment of soil function. See Appendix A., pp. 22-23 for table with unit by unit breakdown by type of disturbance.

Table 7. Yarding System Acres for Alternative 2

Yarding System	Alternative 2 (acres)
Excaline	10
Skyline	673
Skyline/HighBank	11

Skyline/Tethered	99
Tractor	486
Tractor/Excaline	13
Tractor/Skyline	119

Region 1 Soil Quality Standards limit detrimental soil disturbance to an area of 15 percent or less for each activity unit (FSM R-1 supplement no. 2500-99-1 - Soil management). Expected detrimental soil disturbance by harvest system and unit is displayed in Appendix A, pp. 22-23. Exhaustive research has been conducted to determine the major factors causing detrimental disturbance in harvest activities. Research has shown disturbance can range from 1 to over 40 percent, with the key variables being type of equipment used, soil moisture, season of operation, and silvicultural prescription (Rone 2011, Reeves et al. 2011). For estimating the potential amount of increased detrimental disturbance created by proposed activities, the following assumptions were made for ground-based skidding, skyline yarding, combination methods, and temporary road construction.

- Detrimental soil disturbance from *summer ground-based harvest* on areas is estimated at 10 percent of an activity area. Past monitoring on the Lolo NF and Idaho Panhandle NF has shown estimated DSD levels from ground based harvesting to range from 6-14%, including post-harvest fuel treatments (such as mechanical fuel piling and prescribed fire) (Rone 2011, Reeves et al. 2011, and Lolo NF Monitoring Reports 2007-2018).

- Detrimental soil impacts from *skyline and excaline harvest* are estimated at 4% of an activity area. According to monitoring completed on the Lolo National Forest, disturbance from skyline and excaline harvest range from 0-7% with an average of 1-3% (LNF 2018), therefore 4% is a conservative estimate. Additional temporary road disturbance associated with access to skyline/excaline units is included for DSD calculations in table 6, with full table by unit in Appendix A, pp. 22-23.

    1. Some activity units include a combination of harvest methods. In skyline/excaline units with portions of tractor harvest, soil disturbance is estimated to be lower than units designated for tractor. Skyline or excaline units with portions of tractor harvest include units 01, 02, 19, 60, 63. These units have been analyzed using a mid-range estimate for disturbance between tractor (10%) and skyline (4%) of 7 percent soil disturbance.

    2. Skyline units with portions of tethered harvest, will be assumed to have disturbance similar to skyline/tractor units, but may be lower. Skyline/tethered units are 4, 22, 44, 45, and 47. Skyline/tethered units will receive additional monitoring during implementation to determine extent of ongoing disturbance.

- ***Temporary road construction*** is expected to disturb an average area 16 feet in width for slopes less than 50 percent. This is based on the assumption of a road surface 12 to 16 feet wide. The total disturbance area is calculated both as acre and percent within a unit and used in the total DSD calculation in Appendix A, pp. 22-23. There are no temporary road corridors planned on slopes exceeding 35 percent.

- ***Landing construction*** can lead to detrimental soil disturbance including compaction, loss of organic matter, increased erosion and noxious weed infestation. Additions to detrimental soil disturbance created by landings is accounted for in the estimated soil disturbance anticipated for project activities. Where feasible, existing landings will be reused, and all landings will be rehabilitated at the completion of project implementation.

- ***Reuse of existing disturbance*** where feasible, in order to meet the Regional 1 Soil Quality Standards following treatments, which requires at least 85 percent of activity area soil quality to remain in an unimpaired condition as well as complying with other pertinent laws and regulations.

Organic Matter

Harvest operations affect the availability of organic matter and overall nutrient cycling by removal of the stored nutrients in forest biomass, especially if the litter layer is impacted and woody debris are removed. Commercial harvesting removes a larger amount of the nutrients from the site compared to thinning operations which leave fine materials in place. The exact amount of nutrients lost from a particular site would vary with forest types and particular site conditions (Grier et al. 1989). Any project effects would retain coarse woody debris to aid in nutrient replenishment of organic matter and humus stores would remain on the site (Busse et al. 2009).

Soil productivity is defined as a soil's inherent ability to support an expected succession of native plant communities (USDA 1986). Nearly all forest plants have a strong dependence on soil organisms (fungi and microbial communities) for nutrient and gas cycling, as well as extraction of moisture from the soil. In the proposed mechanical treatment units, areas with detrimental levels of soil compaction, displacement, and other physical disturbances caused by harvest activity could reduce the capacity for nutrient cycling, thus affecting the ability of soil organisms and fungi to survive. With the use of best management practices, negative effects to soil productivity would be reduced. Soil micro-organisms from outside the harvest footprint would soon recolonize disturbed areas, as no long-term change in organic matter is expected from proposed project activities. Powers (2002) concludes soil productivity is preserved if the loss of biomass, organic matter, soil porosity and topsoil is limited. Outside of landings and skid trails, large areas (greater than 100 square feet) with detrimental levels of soil disturbance are not expected with the use of Best Management Practices and Timber Sale Contract provisions. Mitigations, including harvest season and retention of coarse woody debris as specified by the Lolo NF Guide to Downed Woody Material (2006), would protect soil biological processes.

Resource Indicator: Soil Stability

Soil stability is tied closely to measurable indicators of soil erosion and sediment delivery potential. Detrimental erosion and sediment delivery are not expected on areas with moderate to low erosion hazard ratings.

Roads

System roads are part of the forest travel management plan; therefore, Region 1 soil quality standards do not apply as their footprint is removed from the productive soil base (R-1 Supplement 2500-14-1, 2014). However, temporary roads constructed to access treatment units are considered part of the productive soil base and are therefore considered 100% detrimentally disturbed. This disturbance is added to the cumulative estimate of negative impacts to be caused by treatment. Unless reclaimed, temporary road corridors will have reduced soil productivity for at least 30 years until native vegetation and forest duff layers are restored. Road length expressed as acres of new temporary road in the effects analysis for detrimental soil disturbance. Approximately 4.4 miles of miles of temporary road construction is proposed for this project.

Temporary roads may also result in concerns for soil stability where underlying mass failure and erosion hazards exist. Proposed temporary road segments were reviewed in the field as well as spatially, and no mass failure concerns were documented for the stable geologic types predominant in the project area.

Temporary roads will be rehabilitated immediately following completion of proposed project activities. Re-contouring activities would not immediately erase impacts to soil productivity, however, normal soil functions would recover more quickly compared to an abandoned road with no restoration as re-contouring and scarification provides a suitable seed bed for native forest vegetation while increasing soil permeability leading to faster recovery of organic matter, total carbon, and total nitrogen (Lloyd et al 2013). For the long-term, infiltration rates improve as freeze/thaw cycles and plant roots increase soil porosity as normal biological function returns to the temporary road base.

Direct and Indirect Effects of Non-Commercial Treatments

Prescribed Fire and Non-Commercial Thinning Treatments

In addition to the commercial harvest treatment activities described above, the Cruzane Mountain project proposal includes fuel reduction treatments, including non-commercial thinning, low severity prescribed burning, and moderate severity prescribed burning on 1,116 acres within the project area.

Non-commercial treatments are a low risk to soil resources. Hand thinning is assumed to cause no additional soil disturbance, and the Lolo Soil Monitoring Reports confirm there is negligible impact associated with non-commercial hand thinning (Lolo Soil Monitoring Reports 2006-2018).

The low and moderate severity fire treatments prescribed for this project are a resource benefit for soils. The forest types within the Cruzane Mountain project area are fire-adapted and controlled fires are an ideal method that is compatible with normal ecosystem functions to remove excess fuels, expedite nutrient cycling, and invigorate seed sources in forest floor materials (Ball et al. 2010; Deluca and Sala 2006).

To mitigate risk of soil erosion associated with exposed forest soils following burning, small diameter slash can be used to cover forest floor openings greater than 100 square feet where high soil burn severity may result in vulnerable soil conditions. With the implementation of Standard Operating Procedures for prescribed burning, the impacts associated with non-commercial activities will meet the intent of National Forest Management Act (NFMA 1976), the Lolo Forest Plan, and Region 1 Soil Quality Standards.

Cumulative Effects

Cumulative effects include the combined effects of forest management activities which overlap in both time and space with those of the proposed actions. For the soil resource, the areas of concern are the treatment units since impacts to soils are site specific. Past activities are considered as a component in the current condition of the soil resource and related disturbance is captured during field review.

In summary, cumulative effects to soils would be minimal and site specific. No additional effects to soils within project activity units are expected to occur beyond those analyzed and disclosed in this document.

Compliance with Laws, Regulations, Policies and Plans

With the implementation of the project design criteria and BMPs, the proposed project is consistent with the goals, objectives, and standards for soil resources set forth in the Lolo Forest Plan. Harvest activities may result in soil disturbance. However, local forest soil monitoring studies and current peer reviewed research has shown soil naturally covers over time. The National Forest Management Act (NFMA 1976) requires that all lands be managed to ensure long-term soil productivity, hydrologic function, and ecosystem health. All activities proposed are consistent with this direction; proposed activities would not result in irreversible damage to the soil resource. Direction found in the 2500 Watershed and Air Management Manual has been applied. Forest Service Manual 2500-14-1 establishes guidelines that limit detrimental soil disturbance to no more than 15% of an activity area. All units would meet Region 1 Soil Quality Standards following project implementation; this assessment is based on a review completed for each unit that considered harvest methods, post-harvest activities, landings, unit access, and remediation.

Legal and Regulatory Compliance

Table 2. Summary of Regulatory compliance for the Cruzane Mountain Soils Resource

Regulation	Alternative 1—No Action	Alternative 2—Proposed Action
The Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974 (16 U.S.C. 1600-1614) (as amended by National Forest Management Act (NFMA) of 1976 (16 U.S.C. 472a) Sections 3, 5, 6	Alternative 1 is in compliance with the Act, because proposed management actions would not take place and no adverse impacts to the soil resource would occur.	Alternative 2 is consistent with the Act, because implementation of mitigation features in the project design would minimize negative impacts to the soil resource. Timber will be harvested from NFS lands only where “soil, slope, or other watershed conditions will not be irreversibly damaged.”
Forest Service Manual 2550, Soil Management, Amend 2500-2010-1 (2010a)	Alternative 1 is in compliance with the FSM, because proposed management actions would not take place and no adverse impacts to the soil resource would occur.	Alternative 2 is in compliance with the FSM, because implementation of mitigation features in the project design would minimize negative impacts to the soil resource.
Forest Service Manual 2550. Soil Management, R1 Supplement 2500-2014-1.	Alternative 1 is in compliance with R1 Standards because proposed management actions would not take place and no adverse impacts to the soil resource would occur.	R1 policy states: “Design new activities that do not create detrimental soil conditions on more than 15 percent of an activity area. In areas where less than 15 percent detrimental soil conditions exist from prior activities, the cumulative detrimental effect of the current activity following project implementation and restoration must not exceed 15 percent.”

Regulation	Alternative 1—No Action	Alternative 2—Proposed Action
Forest Service Handbook 2509.22. Soil and Water Conservation Practices Handbook. R-1/R-4 1988	Alternative 1 is in compliance with the FS Handbook, because proposed management actions would not take place and no adverse impacts to the soil resource would occur.	Alternative 2 is in compliance with the FS Handbook, because implementation of mitigation features referenced in the project design would minimize negative impacts to the soil resource.

References Cited

Bacon, C.R., Lanphere, M. A; 2006. Eruptive history and geochronology of Mount Mazama and the Crater Lake region, Oregon. GSA Bulletin; 118 (11-12): 1331–1359.

Ball, P. N., MacKenzie, M.D., DeLuca T.H., Holben W.E. 2010. Wildfire and Charcoal Enhance Nitrification and Ammonium-Oxidizing Bacterial Abundance in Dry Montane Forest Soils. Journal of Environment Quality 39, no. 4: 1243.

Brown, James & Reinhardt, E. & Kramer, Kylie. (2003). Coarse Woody Debris: Managing Benefits and Fire Hazard in the Recovering Forest. USDA Forest Service - General Technical Report RMRS-GTR.

Busse, M. D., Sanchez, F. G., Ratcliff, A. W., Butnor, J. R. Carter, E. A., Powers, R. F. 2009. Soil carbon sequestration and changes in fungal and bacterial biomass following incorporation of forest residues. Soil Biology & Biochemistry, Vol. 41: 220-227

DeBano, L.F. 2000. The Role of Fire and Soil Heating on Water Repellency in Wildland Environments: A Review. Journal of Hydrology. 231-232. 195-206. 10.1016/S0022-1694(00)00194-3.

DeLuca, T. H., Sala, A. 2006. Frequent Fire Alters Nitrogen Transformations in Ponderosa Pine Stands of the Inland Northwest. Ecology 87, no. 10, 2511–22.

Dumroese, D. S, Jurgensen, M. F., Tiarks, A. E., Ponder F. Jr., Sanchez, F.G., Fleming, R.L., Kranabetter, J.M. 2006. Soil Physical Property Changes at the North American Long-Term Soil Productivity Study Sites: 1 and 5 Years after Compaction. Canadian Journal of Forest Research 36, no. 3 (March 2006): 551–64.

Dumroese, D. S., Abbott, A.M., Rice, T. M., Forest Soil Disturbance Monitoring Protocol: Volume I: Rapid Assessment. Washington, DC: U.S. Department of Agriculture, Forest Service, 2009.

Dumroese, D. S., Jurgensen, M., Thomas, T. 2010. Maintaining soil productivity during forest or biomass-to-energy thinning harvests in the western United States. Western Journal of Applied Forestry. 25(1): 5-11.

Frandsen, W.H. and Ryan, K.C. 1985. Soil moisture reduces belowground heat flux and soil temperatures under a burning fuel pile. Canadian Journal of Forest Research 16:244-248.

Froehlich, H.A. and McNabb, D.H., 1984. Minimizing soil compaction in Pacific Northwest forests. In: E.L. Stone (Editor), Forest Soils and Treatment Impacts, Proc. 6th North Amer-ican Forest Soils Conference, June 1983, University of Tennessee, Knoxville, TN, pp. 1S9-192.

Graham, R.T., Harvey, A.E., Jurgensen, M.F., Jain, T.B., Tonn, R.J., Dumroese, D.S. 1994. Managing Coarse Woody Debris in Forests of the Rocky Mountains. Res. Pap. INT-RP-477. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 12 p. 477

Grier, C.C., Lee, K.M., Nadkarni. M.N. 1989. Productivity of Forests of the United States and Its Relation to Soil and Site Factors and Management Practices: A Review. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 1989.

Han, H.-S., Dumroese, D., Han, S.-K., and Tirocke, J. 2006. Effect of slash, machine passes, and soil moisture on penetration resistance in a cut-to-length harvesting. Int. J. For. Eng. 17(2):11-24.

Han, S.-K., Han-Sup, H., Dumroese, D.S., Johnson, L.R. Soil Compaction Associated with Cut-to-Length and Whole-Tree Harvesting of a Coniferous Forest. Canadian Journal of Forest Research 39, no. 5 (May 2009): 976–89.

Lloyd, R. A., Lohse, K. A., Ferré, TPA. 2013. Influence of Road Reclamation Techniques on Forest Ecosystem Recovery. Frontiers in Ecology and the Environment 11, no. 2 (March 2013): 75–81.

Lolo National Forest, 2007 Soil Monitoring Report. US Department of Agriculture, Forest Service, Missoula, MT.

Lolo National Forest, 2011 Soil Monitoring Report. US Department of Agriculture, Forest Service, Missoula, MT.

Lolo National Forest, 2013 Soil Monitoring Report. US Department of Agriculture, Forest Service, Missoula, MT.

Lolo National Forest, 2015 Soil Monitoring Report. US Department of Agriculture, Forest Service, Missoula, MT.

Lolo National Forest, 2018 Soil Monitoring Report. US Department of Agriculture, Forest Service, Missoula, MT.

Kimsey, M., Gardner, B., Busacca, A.. 2007. Ecological and Topographic Features of Volcanic Ash-Influenced Forest Soils. Coeur d'Alene, ID. Proceedings RMRS-P-44; Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 7-21

McDaniel, P. A., Wilson, M. A. 2007. Physical and Chemical Characteristics of Ash-influenced Soils of Inland Northwest Forests. Volcanic-Ash-Derived Forest Soils of the Inland Northwest: Properties and Implications for Management and Restoration. Proceedings RMRS-P-44; Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. p. 31-45

McIver, J. D., McNeil, R. 2006. Soil Disturbance and Hill-Sediment Transport after Logging a Severely Burned Site in Northeastern Oregon.

McNabb, D.H., Startsev, A.D., Nguyen, H. 2001. Soil Wetness and Traffic Level Effects on Bulk Density and Air-Filled Porosity of Compacted Boreal Forest Soils. Soil Sci. Soc. Am. J. 65:1238-1247. doi:10.2136/sssaj2001.6541238

Miller, R. E., McIver, J.D., Howes, S.W., Gaeuman W.B., 2010. Assessment of Soil Disturbance in Forests of the Interior Columbia River Basin: A Critique. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 2010.

Parsons, A., Robichaud, P., Lewis, S., Napper, C., 2010. Field Guide for Mapping Post-fire Soil Burn Severity. General Technical Report, RMRS-GTR-243

Powers, R. F. 2002. Effects of soil disturbance on the fundamental, sustainable productivity of managed forests. Gen. Tech. Rep. PSW-GTR-183, Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture: 63-82

Reeves, D., Dumroese D., Coleman, M. 2011. Detrimental Soil Disturbance Associated with Timber Harvest Systems on National Forests in the Northern Region.

Sawyers, B. C., Bolding, M.C., Aust, W.M., Lakel W.A. 2012. Effectiveness and Implementation Costs of Overland Skid Trail BMPs. Proceedings of the 16th biennial southern silvicultural research conference. U.S. Department of Agriculture Forest Service, Southern Research Station. 283-289.

Sessions, J., Leshchinsky, B., Chung, W., Boston, K., Wimer, J. 2017 Theoretical Stability and Traction of Steep Slope Tethered Feller-Bunchers, Forest Science, Volume 63, Issue 2, April 2017, Pages 192–200.

USDA Forest Service. 1976. The National Forest Management Act (NFMA) of 1976.

USDA Forest Service. 1986. The Lolo National Forest Plan. US Department of Agriculture, Forest Service, Missoula, MT.

USDA Forest Service. 1988. Forest Handbook. FSH 2509.22, Soil and Water Conservation Practices Handbook. R-1/R-4 Amendment No 1. Missoula, MT. 71 P.

USDA Forest Service. 1989. Sasich, J. and Lamotte-Hagen, K. Lolo National Forest Lands System Inventory. Missoula, MT.

USDA Forest Service. 1995. Forest Service Handbook FSH 2509.13 - Burned-Area Emergency Rehabilitation Handbook, Chapter 20 – Burned-Area Survey and Emergency Treatment Strategy, WO Amendment 2509.13-95-7, Effective January 12, 1995. Washington, D.C.

USDA Forest Service. 1999. Forest Service Manual 2500 – Watershed and Air Management, Chapter 2550 – Soil Management, R-1 Supplement No. 2500-99-1, Effective November 12, 1999. Missoula, MT

USDA Forest Service. 2006. Stewart, C., Applegate, V., Riggers, B., Casselli, J., Beckes, B., Evans, C. 2006. Lolo National Forest Coarse Woody Debris Guide. Missoula, MT: USDA Forest Service, 2006.

USDA Forest Service. 2010. Forest Service Manual 2500 – Watershed and Air Management, Chapter 2550 – Soil Management, Amendment No.: 2500-2010-1, Effective November 23, 2010.

USDA Forest Service. 2011. Rone, G. Summary of Soil Monitoring on the Idaho Panhandle National Forest. Idaho Panhandle National Forest.

USDA Forest Service. 2012. National Best Management Practices for Water Quality Management on National Forest System Lands

USDA Natural Resource Conservation Service. 2015. The Montana Natural Resource Conservation Service Soil Health Strategy. United States Department of Agriculture, Montana Natural Resource Conservation Service.

USGS Wallace 1 degree by 2 degrees Quadrangle, Montana and Idaho; 2000. Harrison, J. E.; Griggs, A. B.,Wells, J. D. I; 1509-A

Williamson, J., Neilsen, W. 2000. The influence of forest site on rate and extent of soil compaction and profile disturbance of skid trails during ground-based harvesting. Canadian Journal of Forest Research, 2000, 30:1196-1205.

Appendix A. Summary of Units, Treatments and Associated Disturbance – Alternative 2

EXISTING CONDITION					DISTURBANCE FROM HARVEST ACTIVITIES				TOTAL DISTURBANCE	
Unit #	*Acres*	*Harvest Method*	*% Existing DSD (before treat-ment)*	*Acres Existing DSD (before treat-ment)*	*% DSD from Treat-ment*	*Acres of DSD from treat-ment*	*% DSD from temp Roads*	*Acres DSD from temp roads*	**Total % DSD (existing + treatment + roads)**	**Total Acres of DSD (existing + treatment + roads)**
1	86	Tractor/ Skyline	2%	1.73	7%	6.04	2%	1.63	**11%**	**9.40**
2	7	Tractor/ Skyline	1%	0.07	7%	0.46	N/A	N/A	**8%**	**0.53**
3	71	Skyline	2%	1.41	4%	2.83	1%	0.56	**7%**	**4.80**
4	11	Skyline/ HighBank	3%	0.34	4%	0.46	N/A	N/A	**7%**	**0.80**
5	8	Skyline	1%	0.08	4%	0.34	5%	0.43	**10%**	**0.85**
6	14	Skyline	1%	0.14	4%	0.57	N/A	N/A	**5%**	**0.71**
7	27	Skyline	3%	0.81	4%	1.08	N/A	N/A	**7%**	**1.88**
8	10	Excaline	1%	0.10	4%	0.38	N/A	N/A	**5%**	**0.48**
9	6	Skyline	3%	0.18	4%	0.25	N/A	N/A	**7%**	**0.43**
10	11	Skyline	1%	0.11	4%	0.44	3%	0.29	**8%**	**0.84**
11	7	Skyline	3%	0.21	4%	0.28	N/A	N/A	**7%**	**0.49**
12	17	Skyline	2%	0.34	4%	0.68	N/A	N/A	**6%**	**1.03**
13	13	Skyline	2%	0.26	4%	0.53	1%	0.14	**7%**	**0.93**
14	7	Skyline	1%	0.07	4%	0.26	N/A	N/A	**5%**	**0.33**
15	27	Skyline	3%	0.80	4%	1.06	N/A	N/A	**7%**	**1.86**
16	6	Skyline	3%	0.18	4%	0.24	N/A	N/A	**7%**	**0.41**
17	13	Skyline	4%	0.52	4%	0.52	N/A	N/A	**8%**	**1.04**
18	13	Skyline	3%	0.38	4%	0.51	N/A	N/A	**7%**	**0.90**
19	13	Tractor/ Excaline	3%	0.40	7%	0.94	N/A	N/A	**10%**	**1.34**
20	69	Skyline	3%	2.06	4%	2.75	N/A	N/A	**7%**	**4.81**
21	42	Tractor	2%	0.84	10%	4.18	1%	0.37	**13%**	**5.39**
22	6	Skyline/ Tethered	3%	0.17	7%	0.39	N/A	N/A	**10%**	**0.56**
23	31	Skyline	3%	0.94	4%	1.25	N/A	N/A	**7%**	**2.19**
24	11	Tractor	2%	0.21	10%	1.07	N/A	N/A	**12%**	**1.28**
25	47	Skyline	3%	1.40	4%	1.86	N/A	N/A	**7%**	**3.26**
27	26	Tractor	1%	0.26	10%	2.57	1%	0.27	**12%**	**3.10**
28	49	Tractor	1%	0.49	10%	4.88	2%	0.76	**13%**	**6.13**
29	67	Skyline	1%	0.67	4%	2.69	N/A	0.08	**5%**	**3.44**
30	28	Skyline	3%	0.84	4%	1.11	2%	0.66	**9%**	**2.61**
31	27	Tractor	2%	0.54	10%	2.72	N/A	N/A	**12%**	**3.26**
32	45	Tractor	2%	0.89	10%	4.46	N/A	N/A	**12%**	**5.35**

41	5	Skyline	3%	0.14	4%	0.19	N/A	N/A	**7%**	**0.33**
42	54	Tractor	1%	0.54	10%	5.38	3%	1.40	**14%**	**7.32**
43	9	Excaline	3%	0.27	4%	0.62	N/A	N/A	**10%**	**0.89**
44	45	Skyline/ Tethered	3%	1.34	7%	3.14	N/A	N/A	**10%**	**4.48**
45	31	Skyline/ Tethered	3%	0.93	7%	2.16	N/A	0.08	**10%**	**3.16**
46	21	Tractor	3%	0.63	10%	2.09	N/A	0.08	**13%**	**2.80**
47	18	Skyline/ Tethered	3%	0.55	7%	1.28	2%	0.33	**12%**	**2.15**
48	30	Skyline	2%	0.59	4%	1.19	N/A	N/A	**6%**	**1.78**
49	35	Skyline	3%	1.04	4%	1.39	N/A	N/A	**7%**	**2.43**
50	17	Skyline	1%	0.17	4%	0.67	N/A	N/A	**5%**	**0.84**
51	4	Skyline	2%	0.08	4%	0.16	N/A	N/A	**6%**	**0.24**
52	7	Skyline	2%	0.15	4%	0.30	N/A	N/A	**6%**	**0.45**
53	21	Skyline	2%	0.41	4%	0.83	N/A	N/A	**6%**	**1.24**
56	13	Skyline	3%	0.38	4%	0.51	N/A	N/A	**7%**	**0.89**
57	18	Skyline	3%	0.54	4%	0.72	4%	0.64	**11%**	**1.90**
60	8	Tractor/ Skyline	1%	0.08	7%	0.54	N/A	N/A	**8%**	**0.62**
61	36	Tractor	3%	1.07	10%	3.58	N/A	N/A	**13%**	**4.65**
63	18	Tractor/ Skyline	2%	0.37	7%	1.29	N/A	N/A	**9%**	**1.65**
64	25	Tractor	3%	0.76	10%	2.53	N/A	0.10	**13%**	**3.39**
65	3	Skyline	1%	0.03	4%	0.14	N/A	N/A	**5%**	**0.17**
66	19	Tractor	2%	0.39	10%	1.93	N/A	N/A	**12%**	**2.32**
67	41	Tractor	2%	0.83	10%	4.15	N/A	N/A	**12%**	**4.98**
68	37	Tractor	3%	1.12	10%	3.73	2%	0.68	**15%**	**5.52**
70	11	Skyline	3%	0.34	4%	0.46	N/A	N/A	**7%**	**0.80**
54A	5	Skyline	3%	0.14	4%	0.19	N/A	N/A	**7%**	**0.33**
54B	14	Skyline	3%	0.42	4%	0.56	N/A	N/A	**7%**	**0.99**
62A	21	Tractor	3%	0.63	10%	2.43	N/A	N/A	**13%**	**3.16**
62B	19	Tractor	2%	0.38	10%	2.32	N/A	N/A	**12%**	**2.78**
62C	6	Tractor	2%	0.12	10%	0.64	N/A	N/A	**12%**	**0.76**
62D	7	Tractor	2%	0.14	10%	0.72	N/A	N/A	**12%**	**0.86**
Acre Total or Ave %	**1411**		**2%**	**32**	**6%**	**92.8**	**2%**	**8.48**	**9%**	**133**

Appendix B. Protocol for determining operability of soils based on soil moisture at 4 to 8 inch depth.

Soil Moisture % Increases Downward	Coarse Soils Loamy sands, fine sandy loam, very fine sands, coarse sands	Light Soils Fine sandy loams, sandy loams, very fine sandy loam	Med. Soils (<35% clay) Sandy clay loam, loam, silt loam, sandy clay loam, clay loam	Heavy Soils (>35% clay) Clay loam, sandy clay, silty clay loam, clay
Dry soils	Dry, loose, single grained flows thru fingers	Dry, loose, flows thru fingers	Powdery, dry, sometimes slightly crusted but breaks down into powdery conditions	Hard, baked, cracked sometimes has loose crumbs on surface
Slightly moist soil	Still appears dry, will not form a ball with pressure	Still appears to be dry; will not form a ball	Somewhat crumbly, but will hold together from pressure	Somewhat pliable; will form ball under pressure. At plastic limit.
Moist soil	Still appears dry, will not form a ball with pressure	Tends to ball under pressure but seldom will hold together	Forms a ball and is very pliable, sticks readily if high in clay.	Easily ribbons out between fingers, has a slick feeling. At plastic limit.
Very moist soil	Tends to stick together slightly, sometimes forms a very weak ball	Forms a weak ball breaks easily, will not stick. Plastic limit or non-plastic.	Forms a ball and is very pliable, sticks readily if high in clay. Exceeds plastic limit.	Easily ribbons out between fingers, has a slick feeling. Exceeds plastic limit.
Wet soils	Upon squeezing, free water may appear. Wet outline is left on hand. Nonplastic.	Upon squeezing free water may appear. Wet outline left on hand.	Can squeeze out free water. Wet outline left on hand.	Puddles and free water forms on surface. Wet outline left on hand.

Source: R5 Soil Scientist and Bob Powers (USDA PSW Soil Scientist)